Belfast City Hospital

Principles of Acid Base Balance Interpretation

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Principles of Acid-base balance interpretation

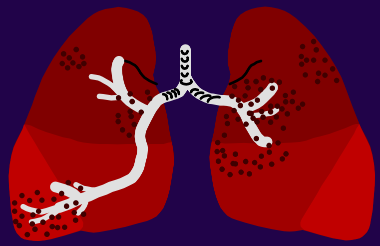
- The material in these slides is not original - it represents a collage taken from several sources
- The graphic representations are mainly based on 'Human Acid-Base Physiology' by Oliver Holmes
  Chapman & Hall Medical, London, 1993, 0-412-47610-X
- A useful internet site is http://www.northland.cc.mn.us/Terry_Wiseth/acid-base%20balance/ppframe.htm
- Line drawing were prepared with SmartDraw. Any feedback or requests (b.silke@qub.ac.U.K.)

Principles of Acid-base balance interpretation

- Acid-base balance -- main concern two ions:
  - Hydrogen (H^+)
  - Bicarbonate (HCO_3^-)
- Derangement is common in disease processes
- H^+ has special significance due to the narrow range compatible with living systems
- Enzymes, hormones and ion distribution are all affected by H^+ concentrations

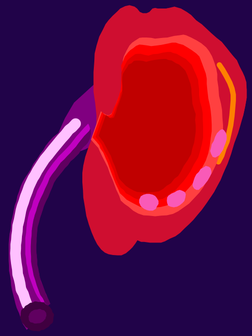
Principles of Acid-base balance interpretation

- **CO_2 25 Mol / day**



$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

- **Non-carbonic acids 70 mmol/day**
  - **Food**
  - **Medication**
  - **Metabolic intermediates**
    - **Lactic acid**
    - **Pyruvic acid**
    - **Acetoacetic acid**



Principles of Acid-base balance interpretation

- E.C.F. acceptable pH range maintained by :
- 1) Chemical buffers

  react very rapidly (< 1 sec)
- 2) Respiratory regulation

  reacts rapidly (sec to min)
- 3) Renal regulation

  reacts slowly (min to hr)

Principles of Acid-base balance interpretation

- Acids can be defined as a proton (H^+) donor
- Molecules that dissociate in solution to $\rightarrow H^+$
- Physiologically important acids include :

  Carbonic acid (H_2CO_3)

  Phosphoric acid (H_3PO_4)

  Pyruvic acid

  Lactic acid

Principles of Acid-base balance interpretation

- Bases can be defined as a proton (H^+) acceptor
- Molecules capable of accepting a H^+ ion
- Physiologically important bases include :

  Bicarbonate (HCO_3^-)

  Biphosphate (HPO_4^{-2})

Principles of Acid-base balance interpretation

A buffer consists of a buffer pair; it is a mixture of a weak acid and its salt

Weak acid HA $\longleftrightarrow$ $H^+ + A^-$

Acid Base

Apply the law of mass action :

$$[H^+] * [A^-] / [HA] = K$$

$$[H^+] = K * [HA] / [A^-]$$

Principles of Acid-base balance interpretation

$- \log[H^+] = -\log K - \log[HA] / [A^-]$

(1) $pH = pK + \log [A^-] / [HA]$ Henderson Hasselbalch

$pH = 6.1 + \log [HCO_3^-] / [CO_2]$

$pH = 6.1 + \log 24 / 1.2 = 7.4$ Normality

Under normal physiological conditions pH can be calculated from the 20:1 ratio of bicarbonate and carbonic acid to lie close to 7.4

Principles of Acid-base balance interpretation

- Maintained within narrow limits

  pH 7.35 to 7.45

⇧ pH = Alkalemia (high blood pH)

⇩ pH = Acidemia (low blood pH)

pH 6.7 to 7.9 compatible with life

Principles of Acid-base balance interpretation

- pH scale expresses $[H^+]$ in H_2O solutions
- Water ionizes to a limited extent to form equal amounts of H^+ and OH^- ions

$$\underset{}{H_2O} \longleftrightarrow \underset{\text{acid}}{H^+} + \underset{\text{base}}{OH^-}$$

Pure H_2O is neutral (pH = 7.0 : $H^+ = OH^-$)

Acid (pH < 7.0 : $H^+ > OH^-$)

Base (pH > 7.0 : $H^+ < OH^-$)

Principles of Acid-base balance interpretation

- Acidosis / alkalosis are physiological conditions where either :

  A relative increase in H^+ ion (acidosis)

  A relative increase in HCO_3^- ion (alkalosis)

- Deviations from this ratio $[HCO_3^-]$ / $[H_2CO_3]$ used to identify acid-base imbalances (pH 7.4 -- 20:1)

- Normal levels 24 and 1.2 mEq / L (HCO_3^- / H_2CO_3)

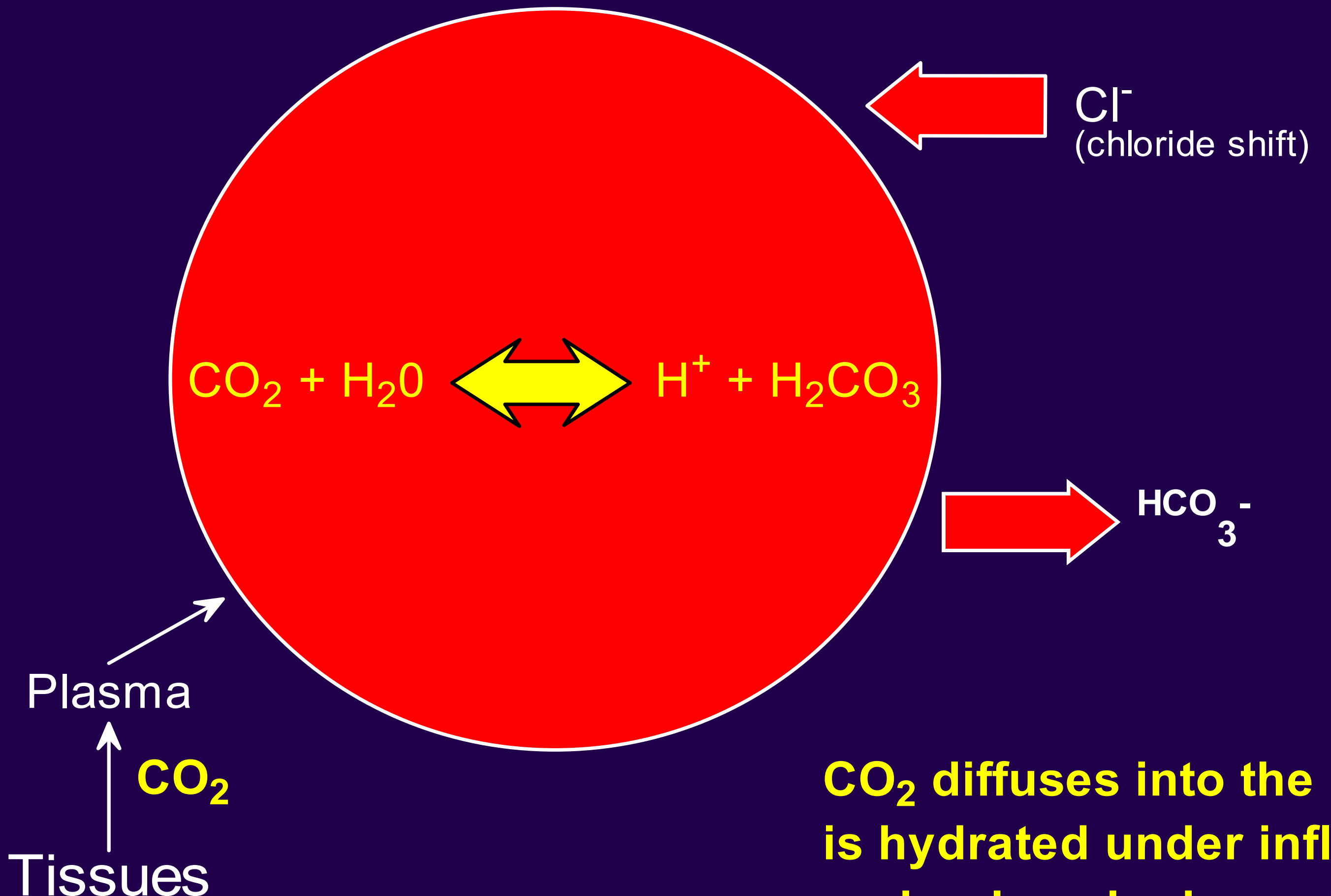
Principles of Acid-base balance interpretation

- **Acidosis a decrease in 20:1 base to acid ratio :**
  An increase in H^+ ion concentration
  A decrease in amount of HCO_3^- ion
  Excessive acid or deficient base

- **Acidosis an increase in the base to acid ratio :**
  An decrease in number of H^+ ions
  An increase in amount of HCO_3^-
  Base excess or acid deficit

CARBON DIOXIDE DIFFUSION

Red Blood Cell



CO_2 diffuses into the RBC and is hydrated under influence of carbonic anhydrase. HCO_3^- diffuses into the plasma.

Principles of Acid-base balance interpretation

The ratio $[HCO_3^-] / [H_2CO_3]$ determines the acid-base status

pH = 6.1 + log 24 / 1.2 = 7.4 (Normal status)

Add 12 mM of strong acid to 1L of E.C.F.

pH = 6.1 + log 12 / 13.2 = 6.06 (Closed system)

pH = 6.1 + log 12 / 1.2 = 7.1 (Open system)

Principles of Acid-base balance interpretation

- To minimize the pH alteration requires alteration of the $[HCO_3^-]$ / $[H_2CO_3]$ ratio
- The ability to regulate the PCO_2 limits the pH change that would otherwise occur ; this makes the HCO_3^- / H_2CO_3 system a near perfect buffer (respiratory adjustment)
- The HCO_3^- level is under separate renal physiological control (metabolic adjustment)

Principles of Acid-base balance interpretation

- Intracellular Buffers
  - Proteins
  - Haemoglobin
  - Phosphate
- Bone buffers
- Extracellular Buffers
  - Proteins
  - Phosphate
  - Bicarbonate

Acidosis - an excess of unwanted acid in the blood; pH may be normal

Alkalosis - an excess of unwanted alkali in the blood; pH may be normal

Principles of Acid-base balance interpretation

- Most important buffer : CO_2- bicarbonate pair
- Other buffers termed non-bicarbonate
- Legitimate to consider these ‘protein buffer’
- Blood buffer capacity is approx.. 48 mmol
- 50% of buffering due to CO_2- bicarbonate pair
- Acid base status cannot be assessed purely from a knowledge of the bicarbonate status

Principles of Acid-base balance interpretation

Whole blood buffering of an acid load

CO_2	Non-HCO_3^- buffers		100%
Fixed acid	Bicarbonate	Plasma	35%
		RBC's	18%
	Haemoglobin		35%
	Plasma proteins		7%
	Phosphate		5%

Principles of Acid-base balance interpretation

- **Components of Acid-base disorder**

  Respiratory indicated by PCO_2

  Metabolic indicated by the blood line shift

- **Standard bicarbonate**

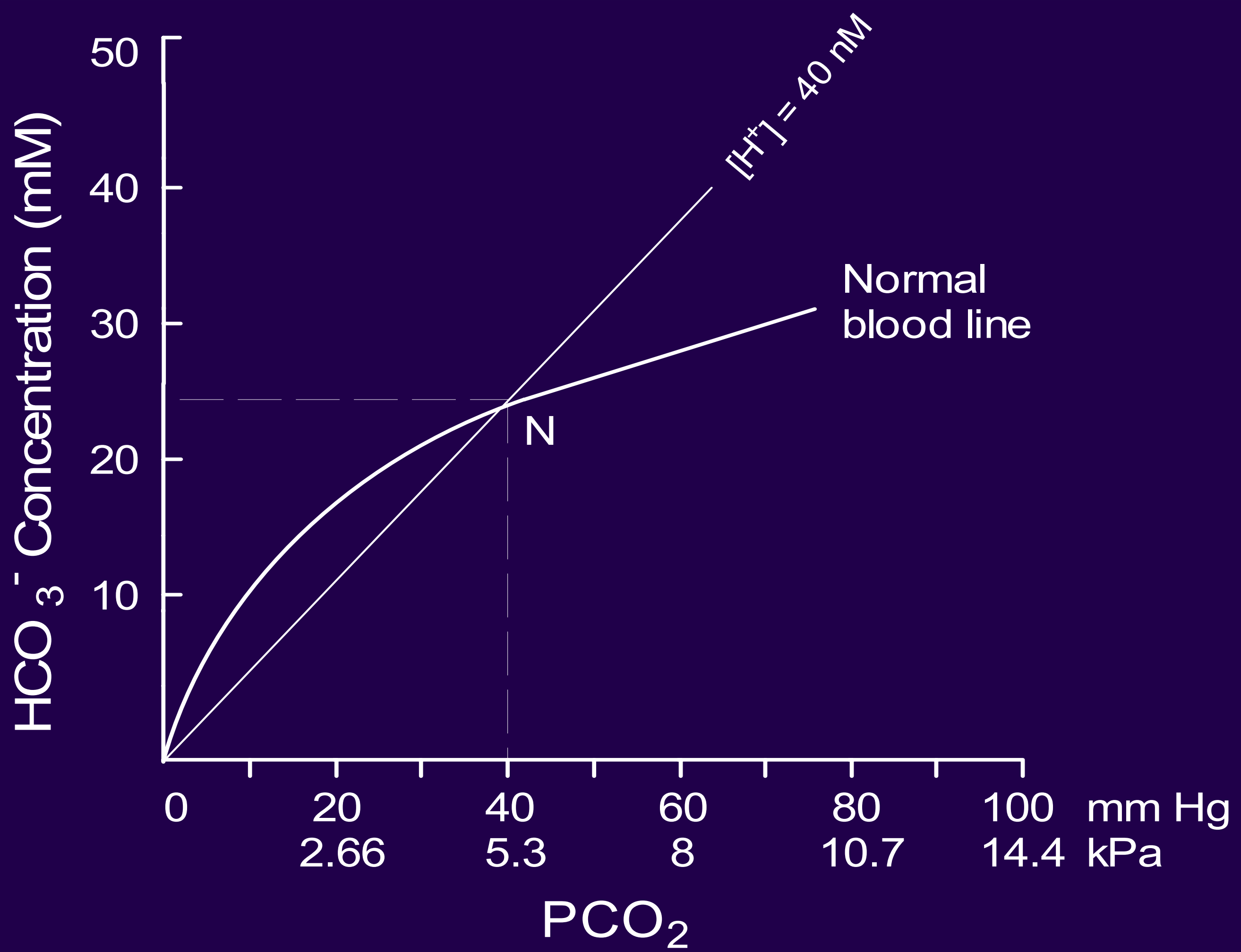
  The bicarbonate concentration in mM in the plasma of oxygenated whole blood equilibrated with a PCO_2 of 5.3 kPa at 37°C

  < 22 mM metabolic acidosis : > 26 mM alkalosis

Principles of Acid-base balance interpretation

- The variables of the Henderson-Hasselbalch equation are $[H^+]$, $[HCO_3^-]$ and $[CO_2]$
- Each pair - can be plotted on linear or log scale
- The following convention has been adopted to plot $[HCO_3^-]$ as a linear function of $[PCO_2]$
- To determine the standard $[HCO_3^-]$, $[PCO_2]$ is manipulated and these changing relationships are easy to visualize and interpret

Principles of Acid-base balance interpretation



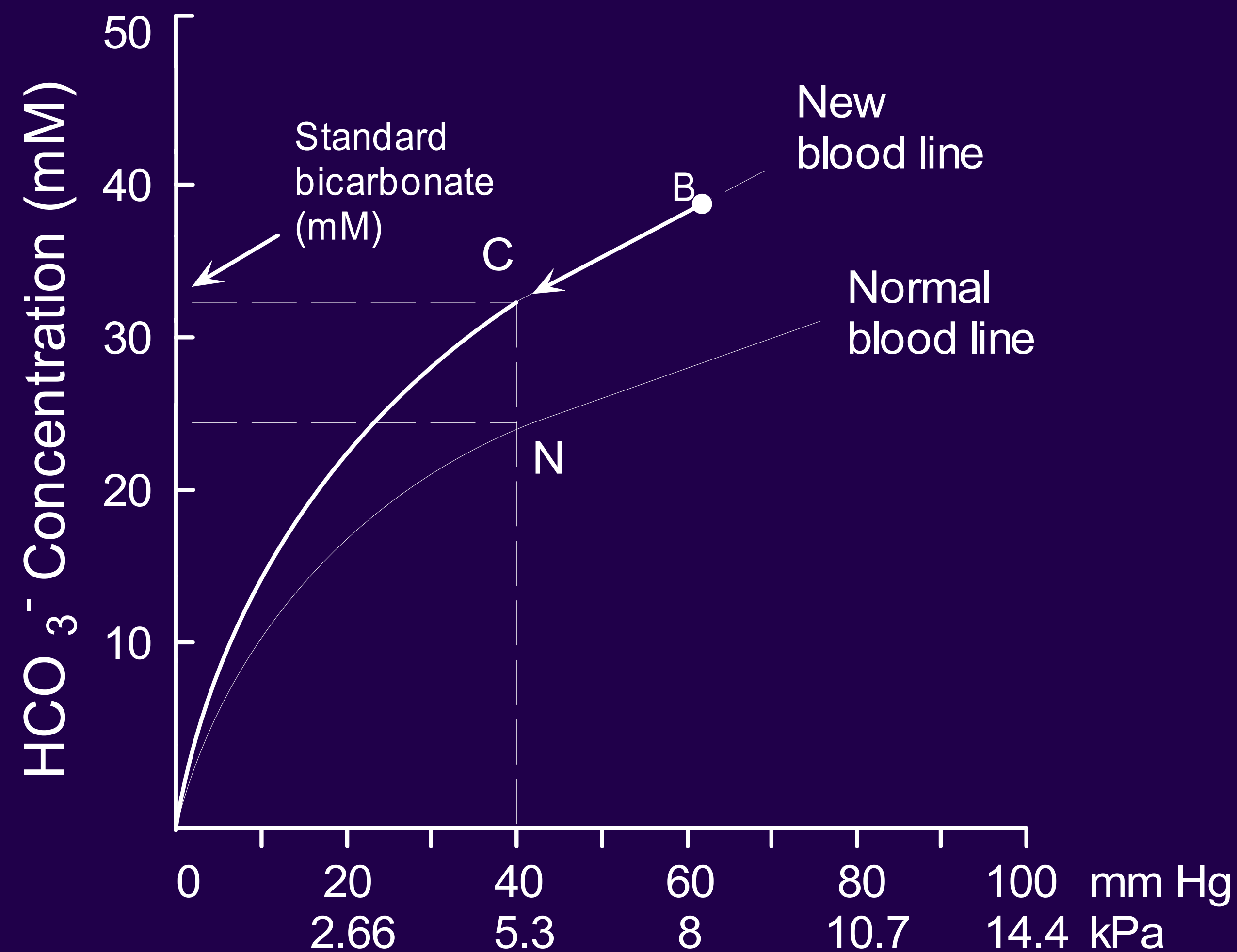
Principles of Acid-base balance interpretation

- **In the system**
  Iso-pH lines are linear and pass through origin
  pH relationships easy to appreciate
  Blood line is curved, resembling the carbon dioxide dissociation curve
  However not desirable as a normogram method
- **Siggaard-Andersen normogram - uses log plots for both axes and consequently the third variable is a straight line (BE & buffer base)**

Principles of Acid-base balance interpretation

- Standard HCO_3^- - imperfect measure of acid-base status. Incomplete representation of buffers
- Only estimates the HCO_3^- / H_2CO_3 contribution
- Measure both [HCO_3^-] and [Pr^-] components because the latter is 50% of buffering capacity
- This measure is termed the Base Excess
- To measure directly a process of ‘back titration’

Principles of Acid-base balance interpretation



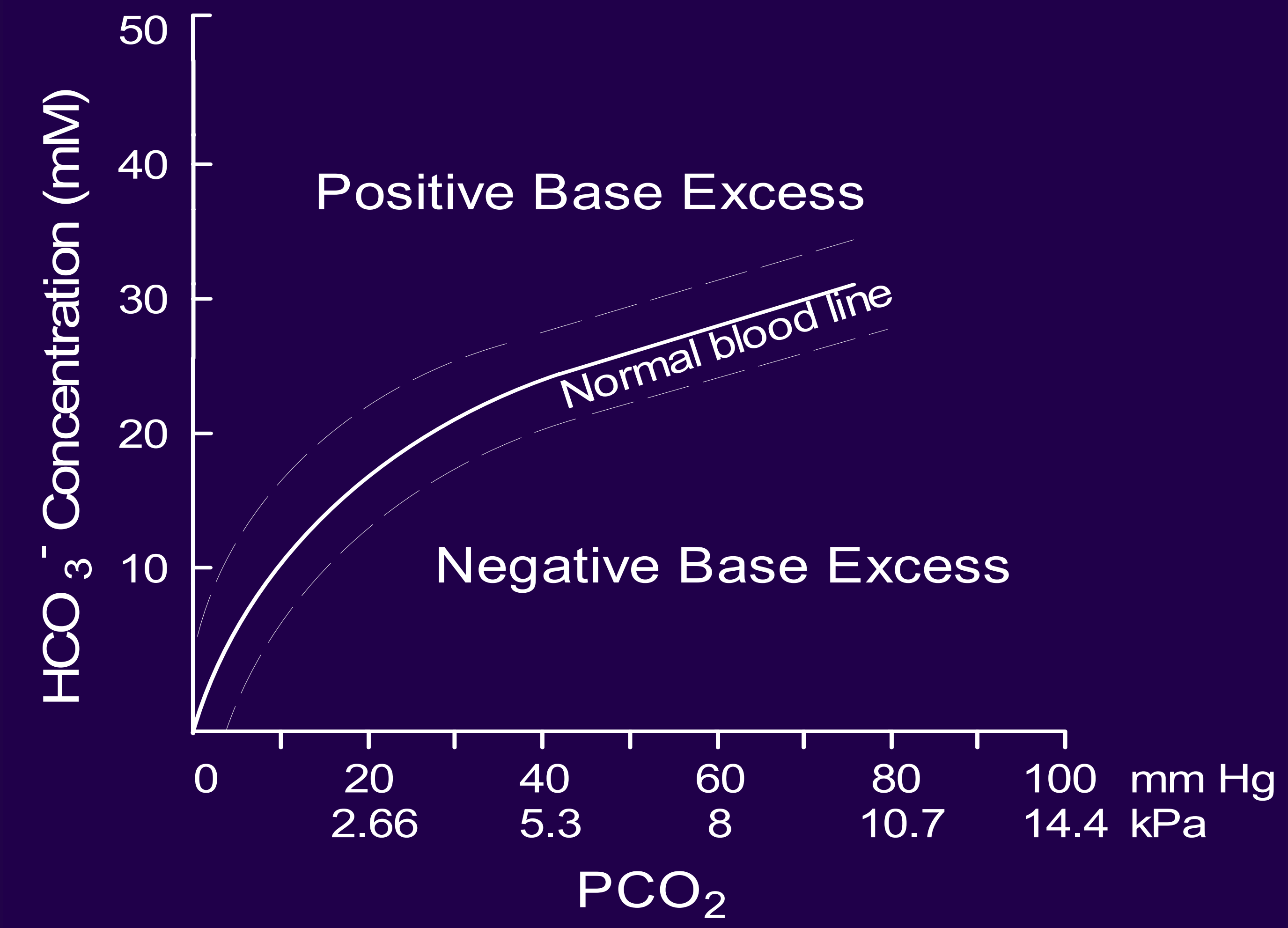
Principles of Acid-base balance interpretation

- Base Excess is the change from normal of the concentration of [HCO_3^-] and [Pr^-] buffer base
- To estimate directly, first remove respiratory component. Equilibrate blood at 37°C and PCO_2 of 5.3 kPa and 'back titrate' to pH 7.4
- Quantitatively Base Excess is the amount of acid (mM) to be added to 1 L of whole blood to return pH to 7.4 (normal range $\pm$ 2.5 mM)

Principles of Acid-base balance interpretation

- Knowledge of the HCO_3^- and PCO_2 defines a point on the acid-base chart
- Insufficient information to calculate Base Excess and estimate the extent of blood buffering
- BE calculated from amount of strong acid or base required to restore pH (back titration)
- Siggaard-Andersen normogram - obviate need

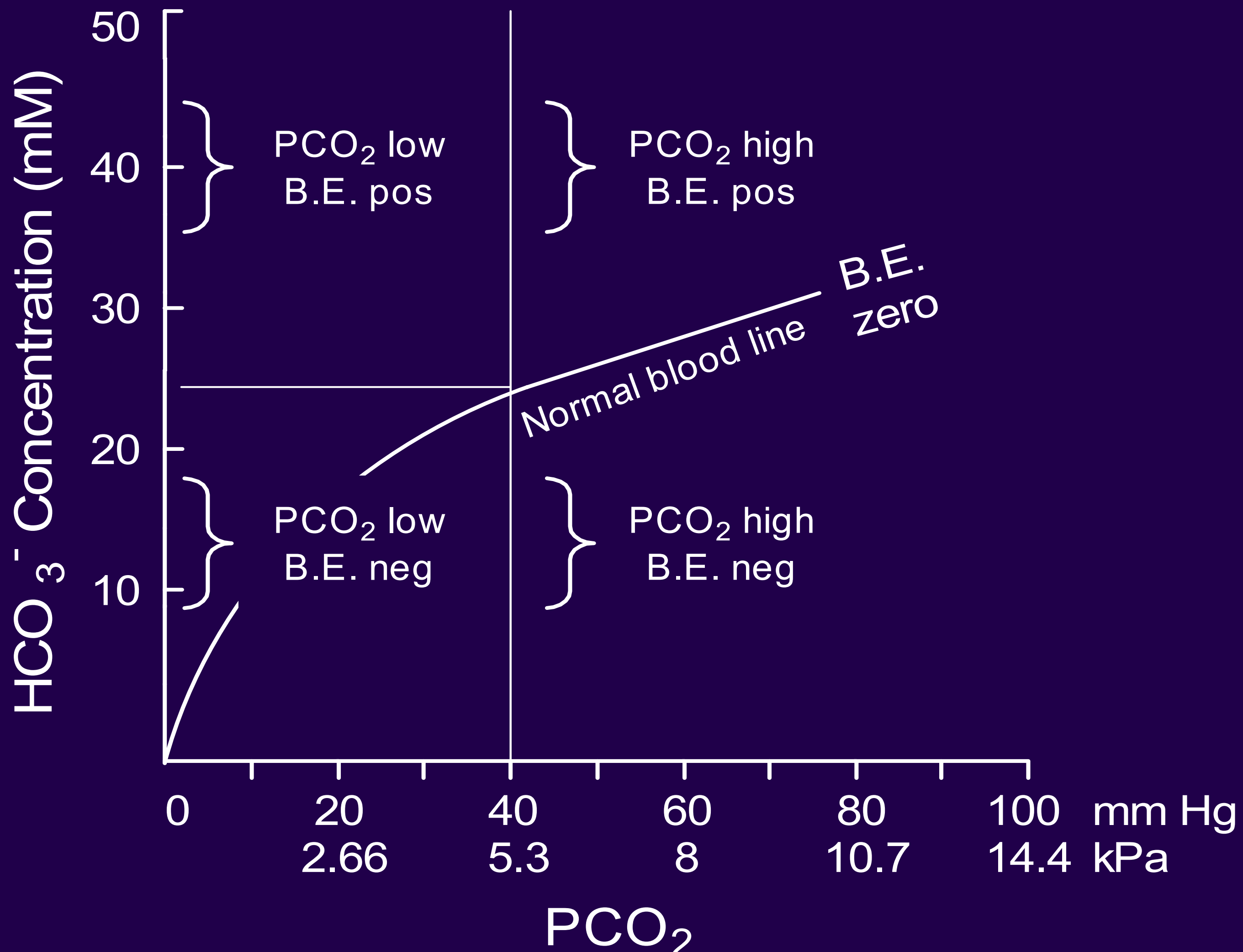
Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

	Compen-sated	Respiratory component	Metabolic component
Respiratory acidosis	No	High	Zero
	Yes	High	High
Metabolic alkalosis	No	Zero	High
	Yes	High	High

Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

- Carbon dioxide is a respiratory gas
- In aqueous solution it is a weak acid

  $CO_2 + H_2O = H^+ + HCO_3^-$
- Hypoventilation, with CO_2 accumulation, acidification of ECF - respiratory acidosis
- Hyperventilation with CO_2 ‘washout’ leads to respiratory alkalosis

Principles of Acid-base balance interpretation

- Hypoventilation - pulmonary ventilation reduced
- Respiratory movements may be increased
- Conditions causing respiratory acidosis:

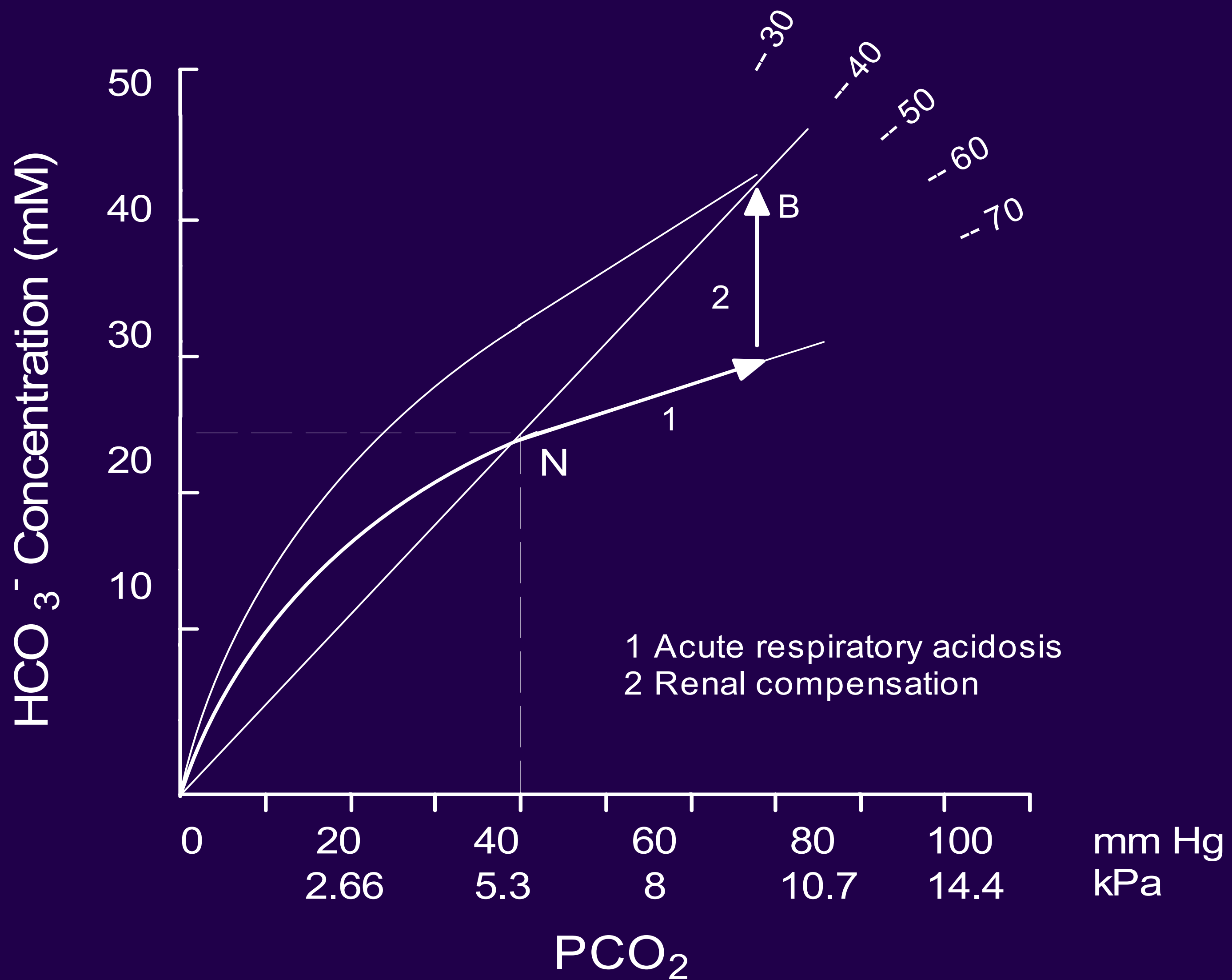
  Depressed respiratory centre (drug abuse)

  Obstructive airways disease

  Inhaled foreign object

  Bronchoconstriction (Acute asthma)

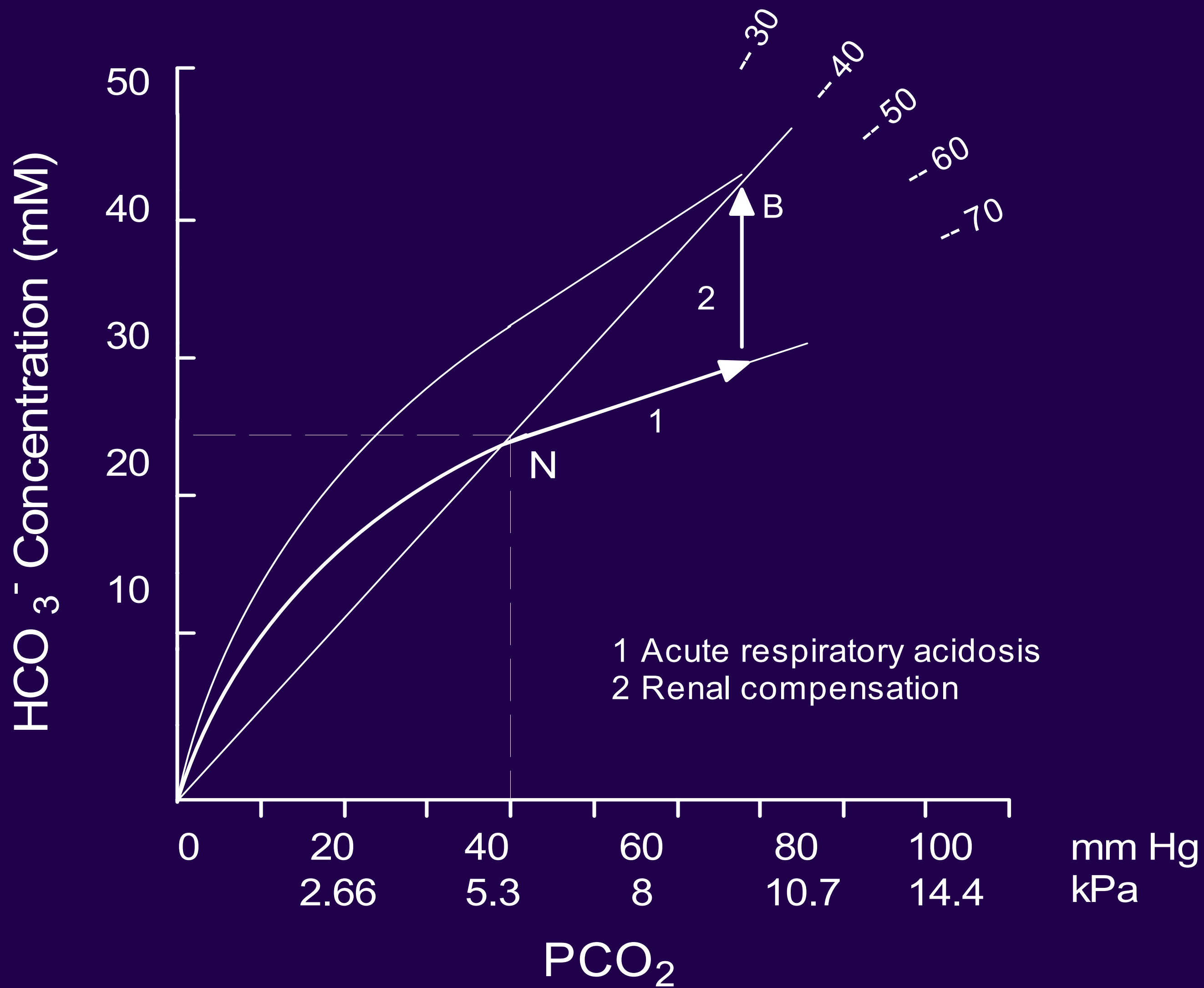
Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

	Uncompensated	Renal (HCO_3^-) compensation
PCO_2	High	High
mm Hg	80 (10.7)	80 (10.7)
[HCO_3^-]	High	High
mM	29	48
[H^+]	High	Normal
nM	67	40
	Acute (min to hr)	Chronic (hr to days)

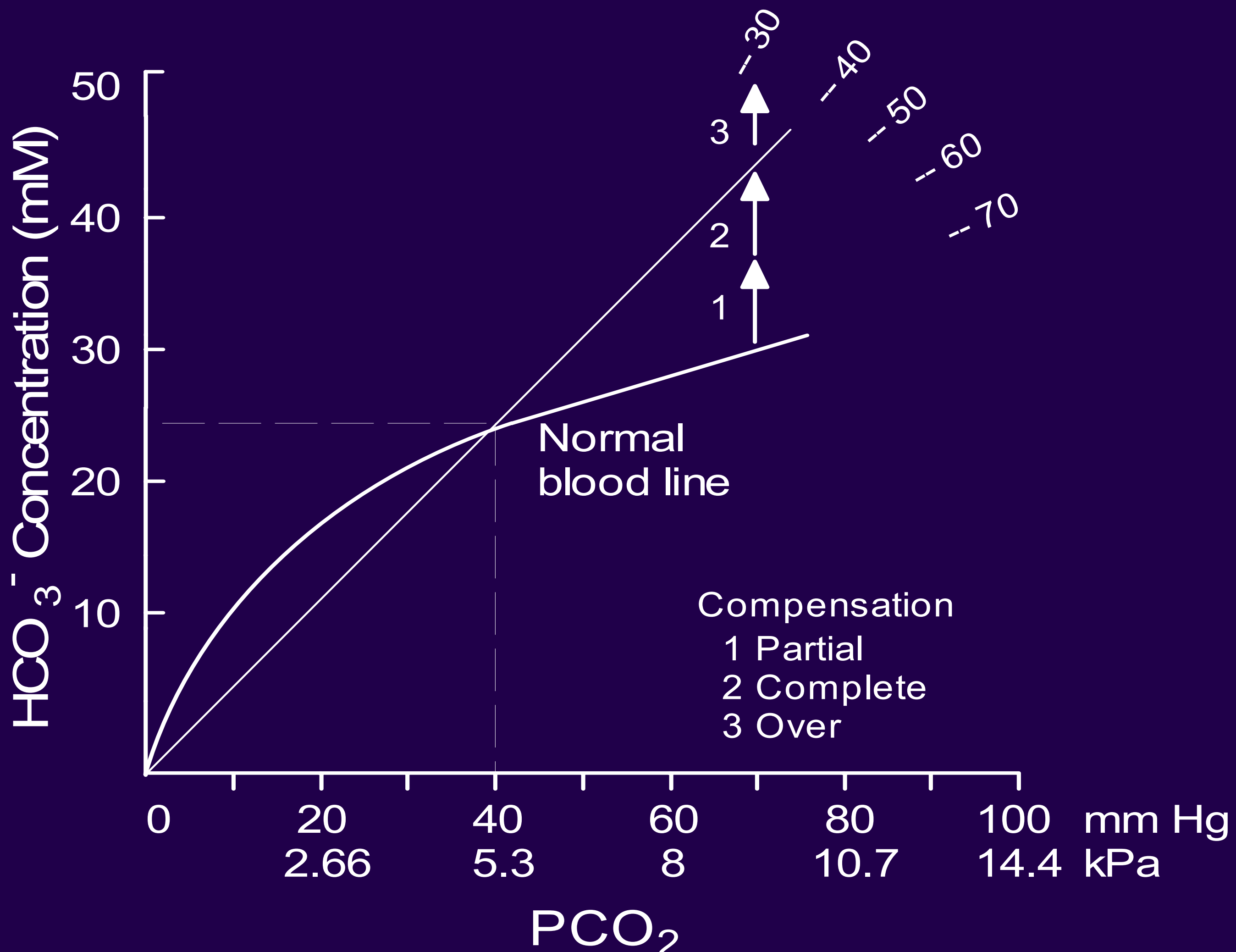
Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

- Respiratory acidosis - increase in PCO_2
- Rise in H^+ is buffered by blood buffers
- Acute - lack of physiological compensation
- Compensation is due to renal HCO_3^- retention
- Compensation not restore blood chemistry
- Adjusts $[HCO_3^-]$ / $[CO_2]$ ratio to restore pH

Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

- Hyperventilation - pulmonary ventilation ↑
- Loss of CO_2 exceeding production rate
- Conditions causing respiratory alkalosis:

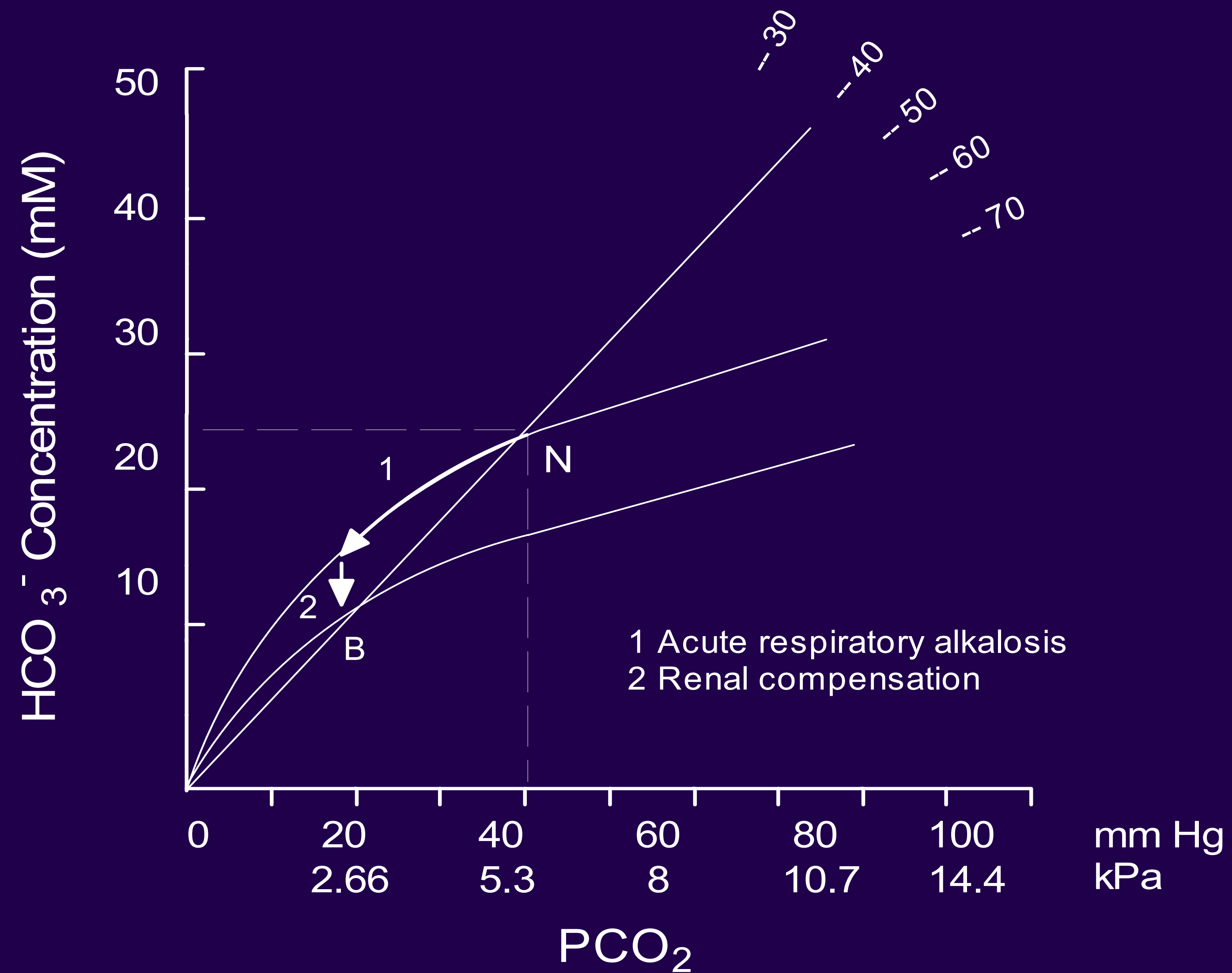
  Anxiety and emotional disturbances

  Salicylate poisoning (overdose)

  Assisted ventilation

  High altitude (low environmental O_2)

Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

- Non-respiratory disturbances termed metabolic
- Large variety of primary abnormalities --> in excess of non-respiratory acid / alkali
- Excessive intake of acid or alkali or renal defects
  - Ingestion of acid or alkali (mouth, injection etc.)
  - Excessive GI losses (vomiting, diarrhoea)
  - Abnormal metabolism (diabetes mellitus)
  - Renal failure or tubular defects

Principles of Acid-base balance interpretation

- Metabolic acidosis may result from exercise
- Accumulation of tissue metabolites, including lactic acid consequent on anaerobic metabolism
- Diabetes mellitus accumulation of ketone bodies

  Aceto-acetic acid and β-OH butyric acid
- Non-volatile or fixed acids - not blown off
- Other diseases include CHF and renal failure

Principles of Acid-base balance interpretation

Initial response to acute metabolic acidosis

$H^+ + Pr^- \Rightarrow HPr$

$H^+ + HCO_3^- \Rightarrow H_2O + CO_2$

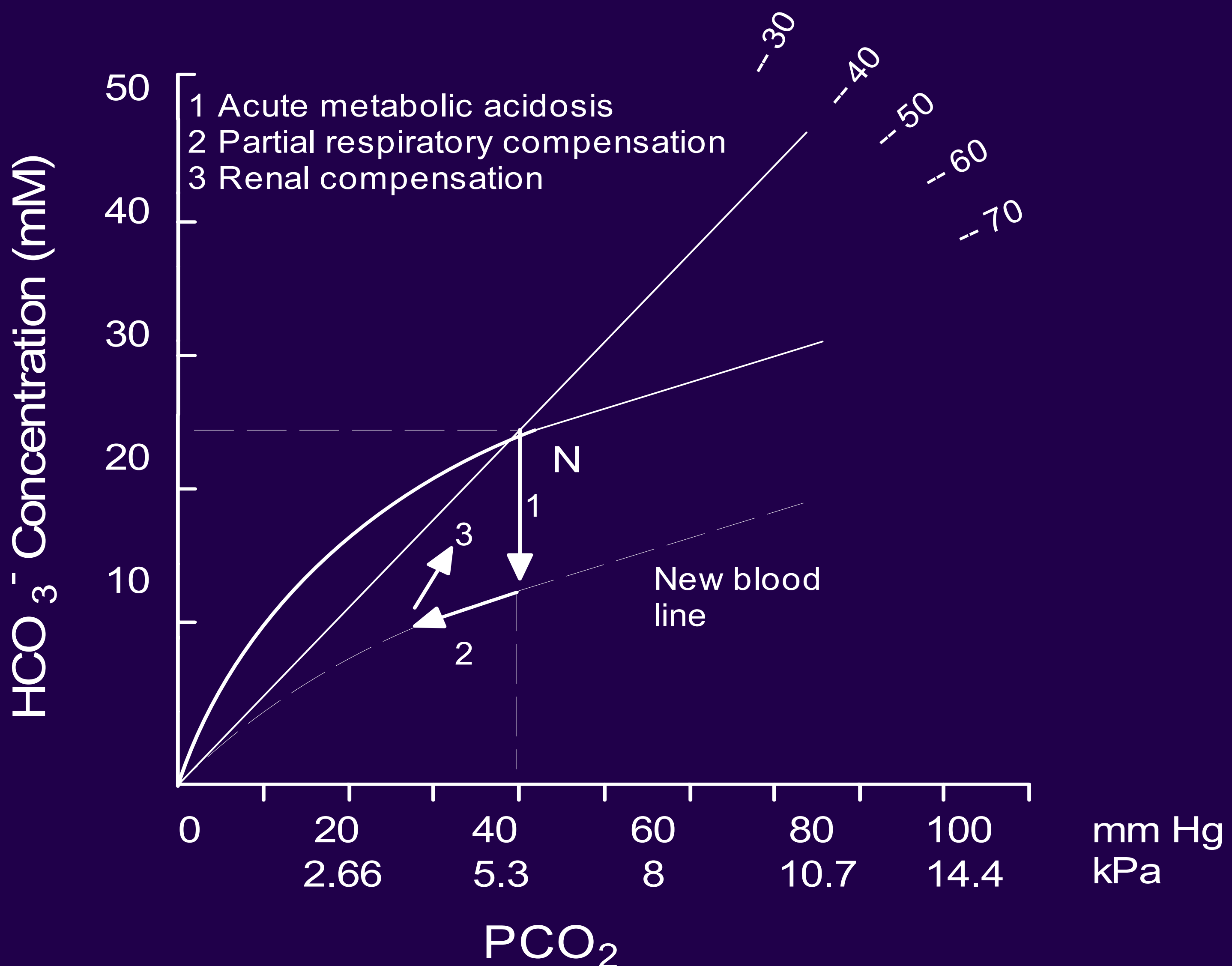
$\downarrow$ Buffer base in blood

$\downarrow$ Excreted from the lungs

Principles of Acid-base balance interpretation

	Uncompensated	Respiratory (PCO_2)	Renal (HCO_3^-)
PCO_2	High	High	High
mm Hg	80 (10.7)	72 (9.4)	50 (6.66)
$[HCO_3^-]$	Normal	Low	Low
mM	40	30	35
$[H^+]$	Low	Low	Low
nM	12	10	17
	Acute (min to hr)	Chronic (hr to days)	Chronic (hr to days)

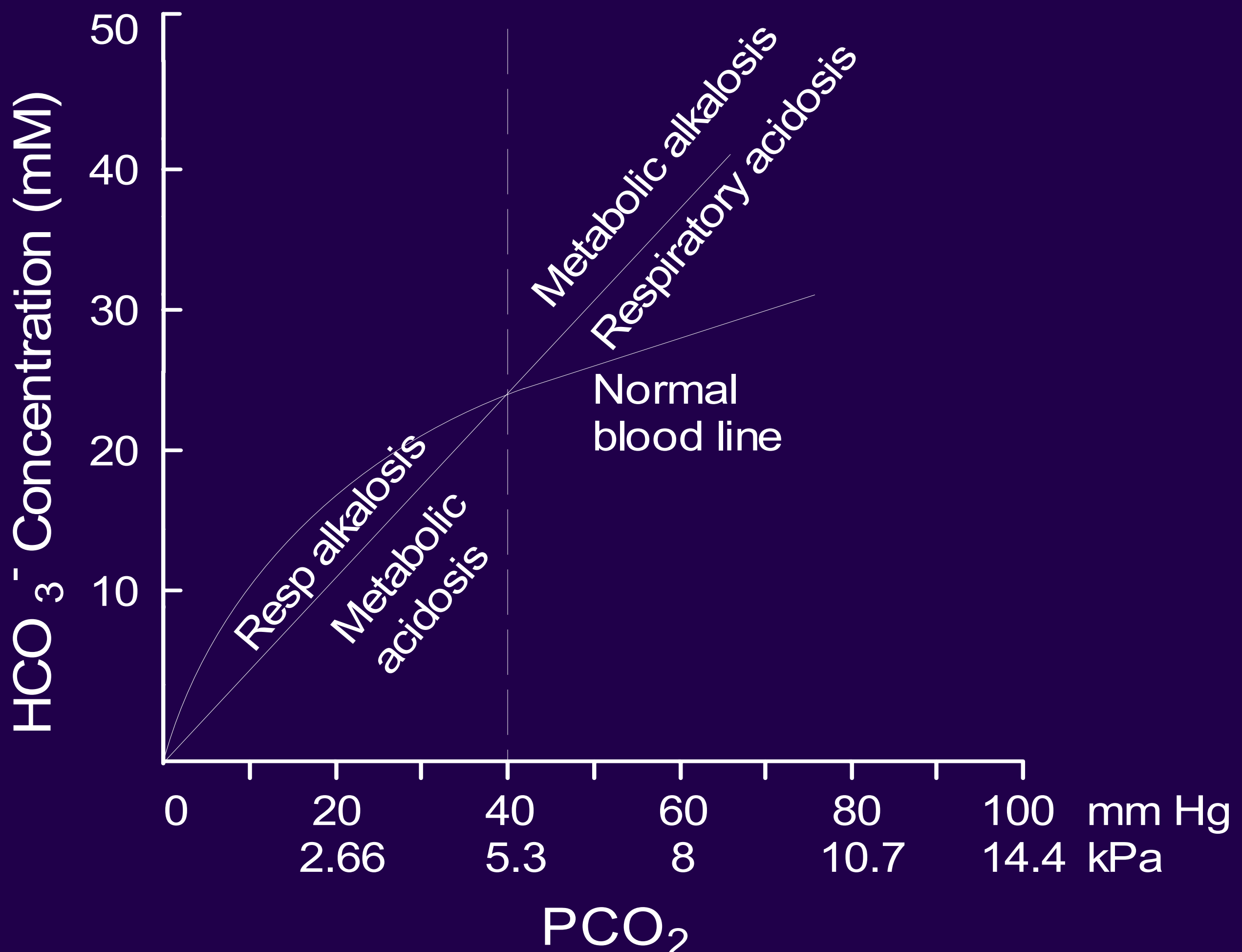
Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

- Fixed acid accumulation usually gradual : uncommon for acute uncompensated process
- Uncompensated would be represented as a reduced HCO_3^- and pH without change in PCO_2
- Partial respiratory compensation is achieved by a further reduction in PCO_2
- Renal compensation involves HCO_3^- retention

Principles of Acid-base balance interpretation

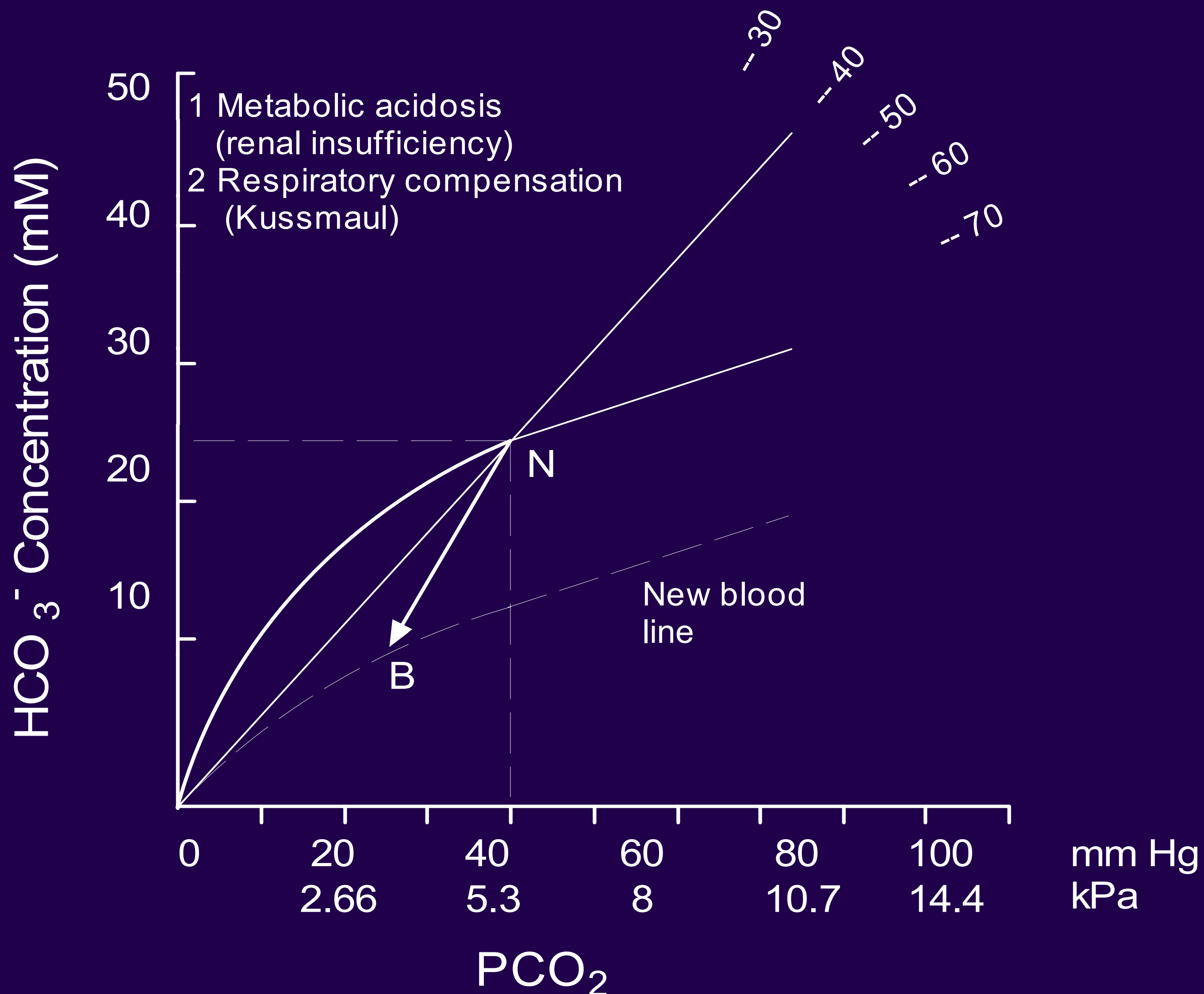


Principles of Acid-base balance interpretation

- 80 yr. old male
- Nursing home
- Previous CVA * 3
- Debilitated
- Poor QOL
- Recent gradual deterioration with mental obtundation

O_2	10.28 kPa
pCO_2	3.04 kPa
B.E.	-10.5 mm/l
pH	7.34
Na^+	135.4 mEq/l
K^+	7.7 mEq/l
Cl^-	100.2 mEq/l
Cr.	930 umol/l

Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

- **Aspirin - therapeutic dosage**

  Central respiratory stimulation (alkalosis)

  Renal compensation with HCO_3^- loss

  Compensated respiratory alkalosis

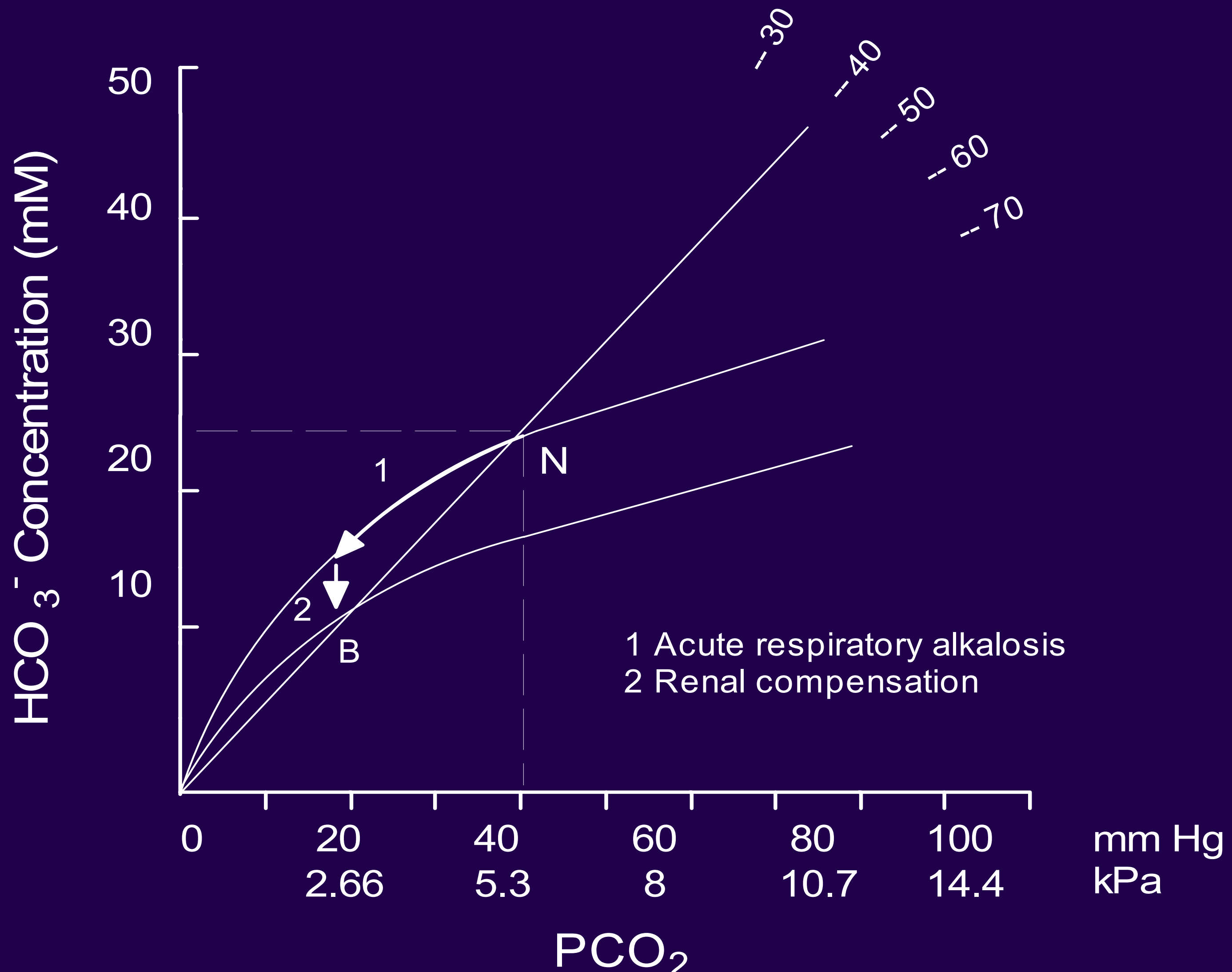
- **Aspirin overdose with toxicity**

  Changes resemble metabolic acidosis

  Low plasma HCO_3^- and normal PCO_2

  Combined respiratory and metabolic acidosis

Principles of Acid-base balance interpretation

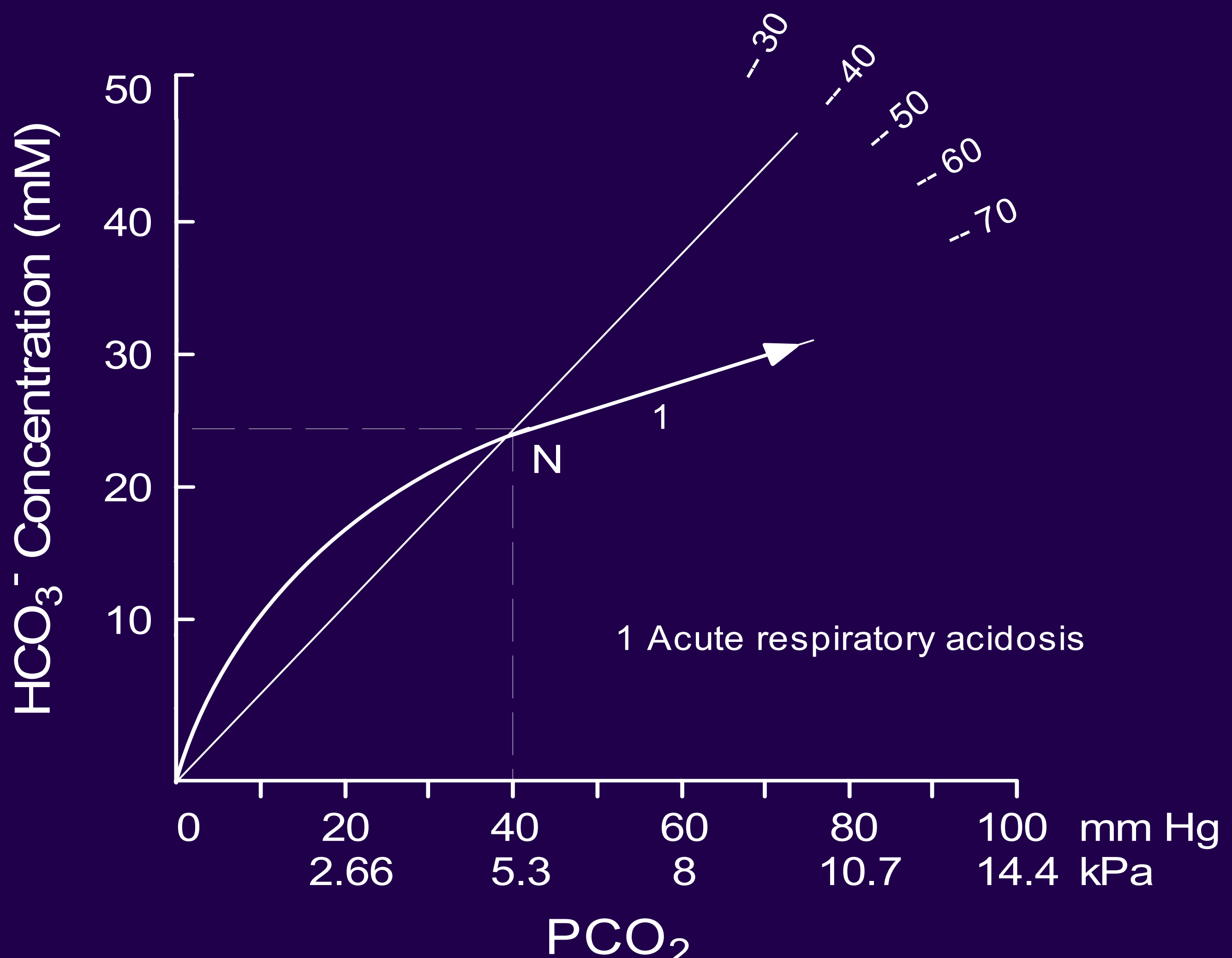


Principles of Acid-base balance interpretation

- 25 yr. old female
- Chronic depression
- Unconscious
- Overdose barbiturates
- Hypoventilation

- pH 7.25
- pCO_2 8.0 kPa
- pO_2 10.7 kPa
- HCO_3^- 29
- BE 0 mM

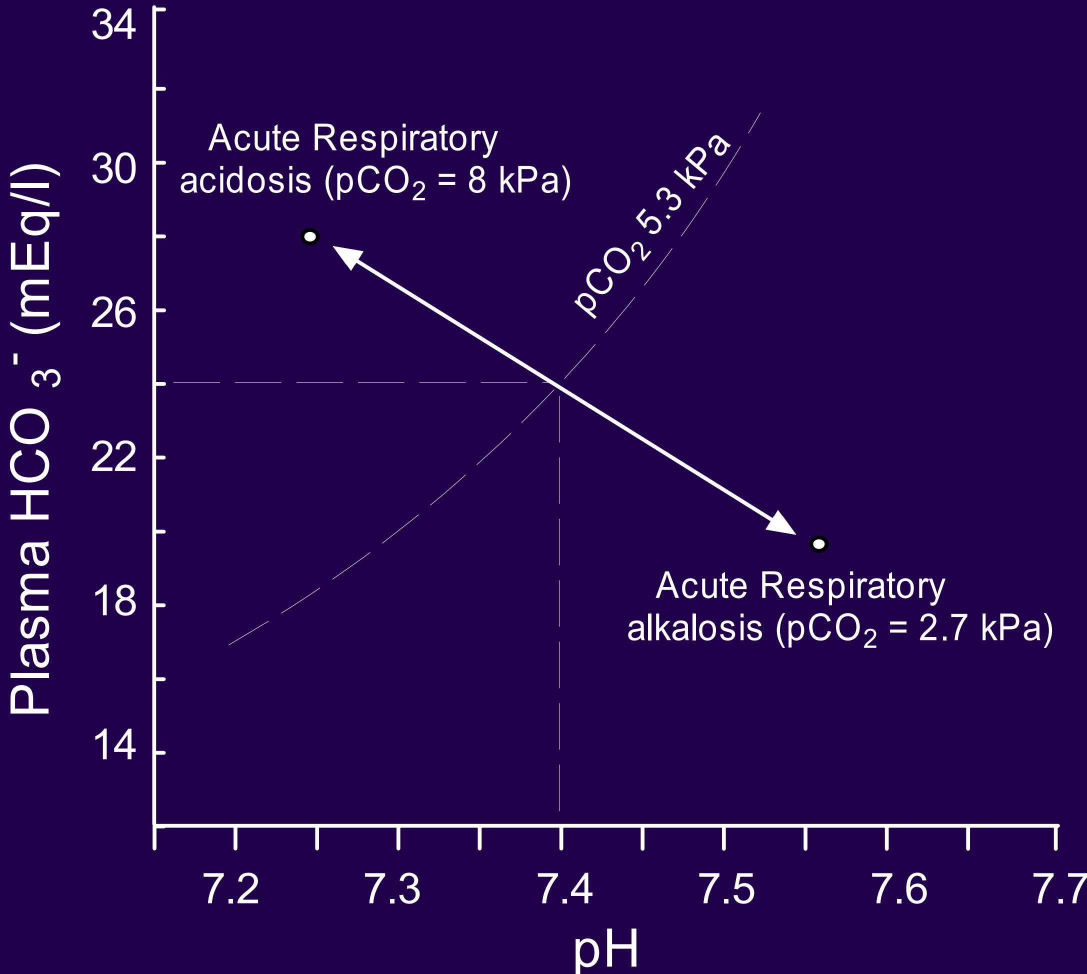
Principles of Acid-base balance interpretation



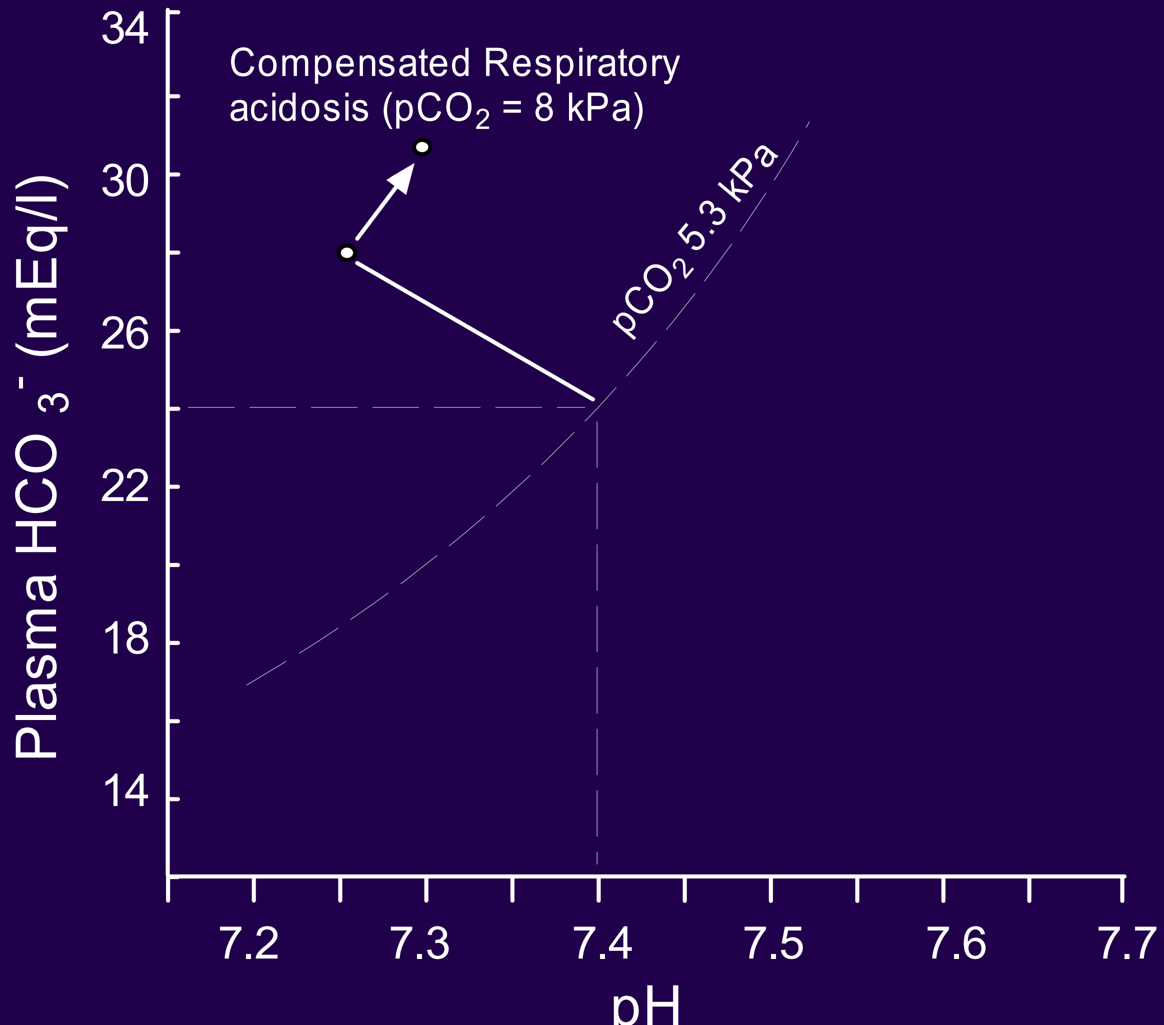
Principles of Acid-base balance interpretation

- It is also possible to represent change in acid base status after Davenport (ABC of acid-base chemistry) in terms of pH / HCO^-_3 relationships
- Changes in CO_2 move the relationship up and to the left (increase) or down / right (decrease)
- Metabolic changes (addition or subtraction of acid) are represents as ‘Iso-CO_2 line’ changes

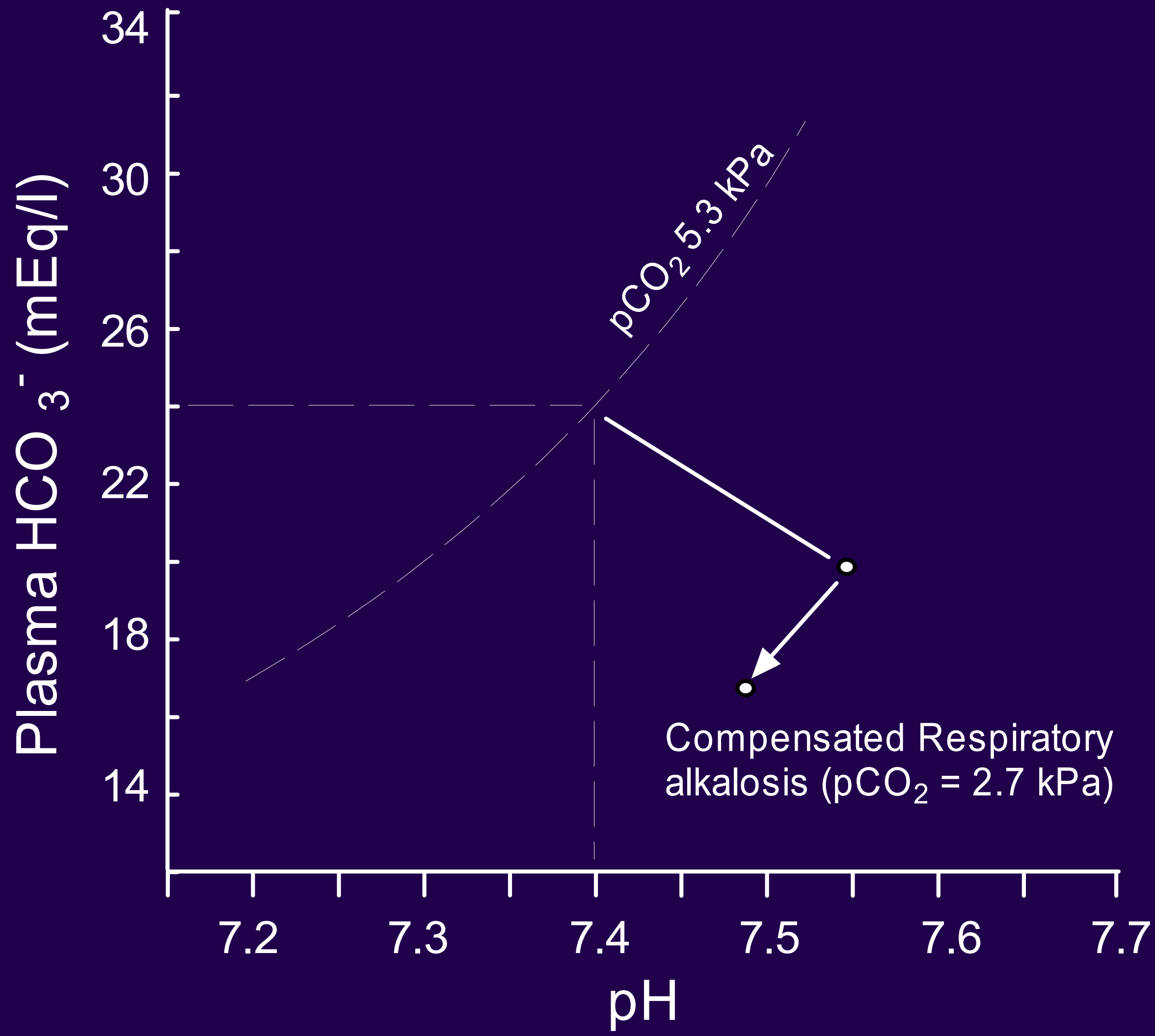
Principles of Acid-base balance interpretation



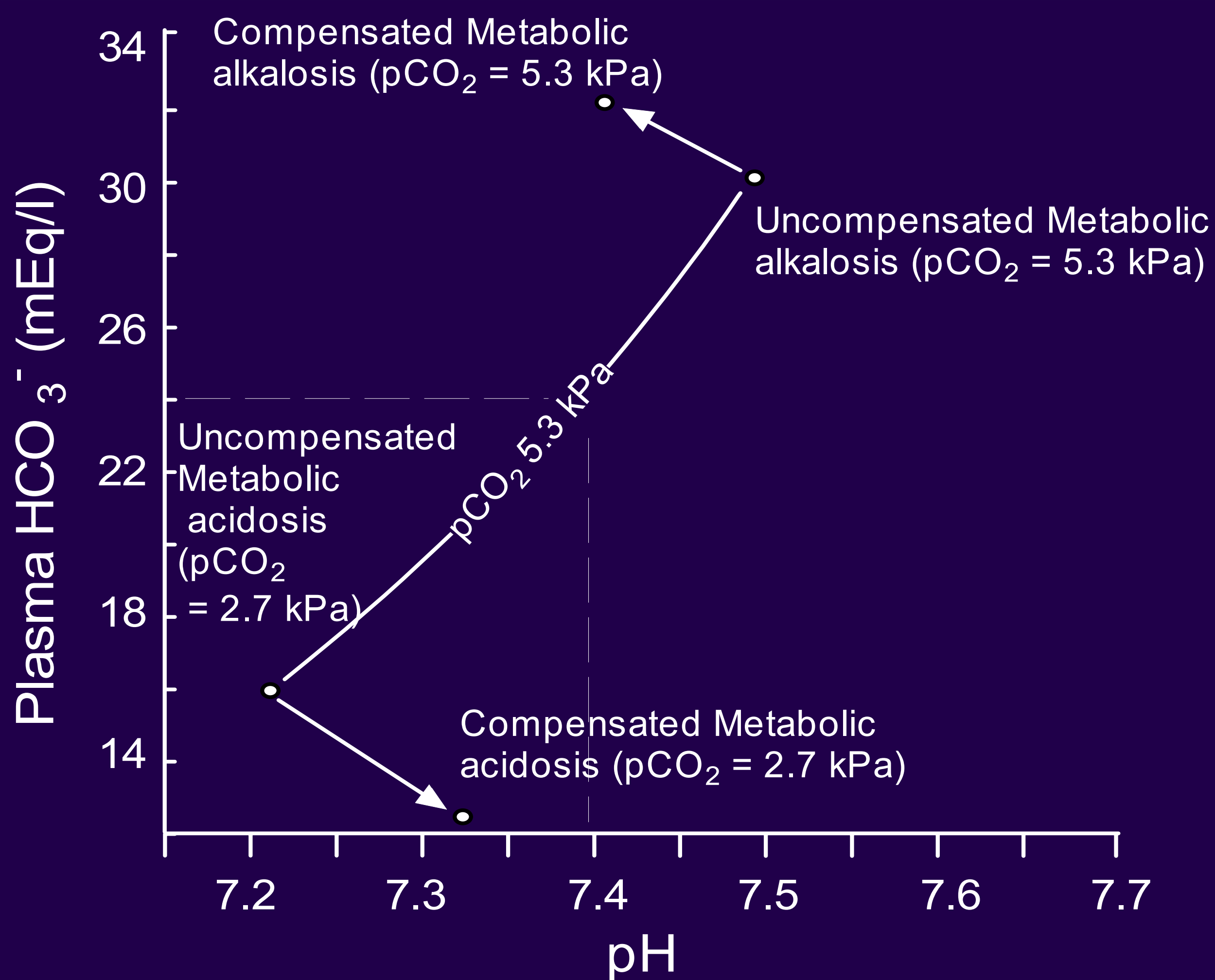
Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

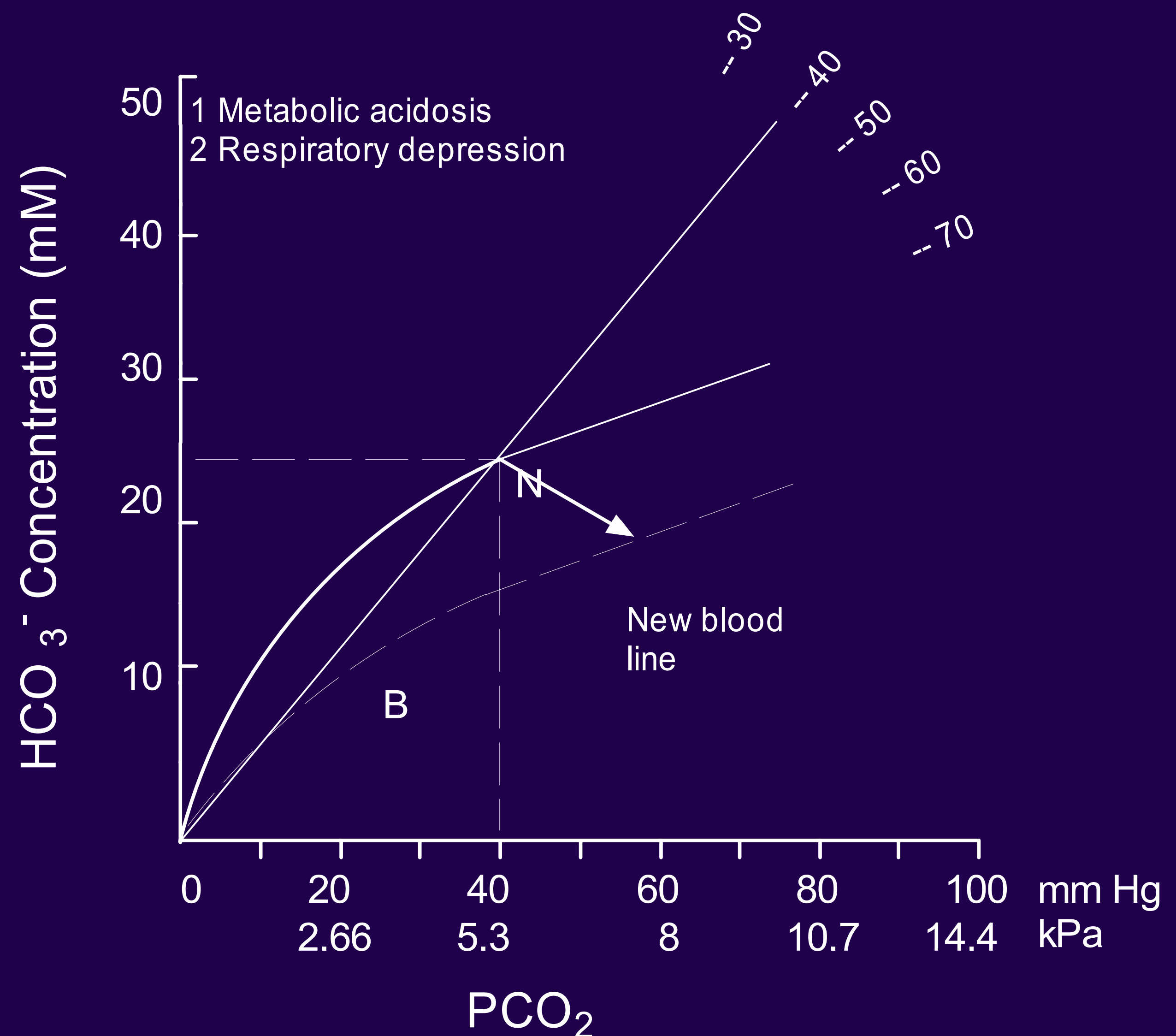


Principles of Acid-base balance interpretation

- 18 yr. old male
- Drink driving
- RTA & unconscious
- Multiple injuries, shock, rib fractures
- Crushed legs

- pH 7.1
- pCO_2 8.0 kPa
- pO_2 10.7 kPa
- HCO_3^- 18
- BE - 10 mM

Principles of Acid-base balance interpretation

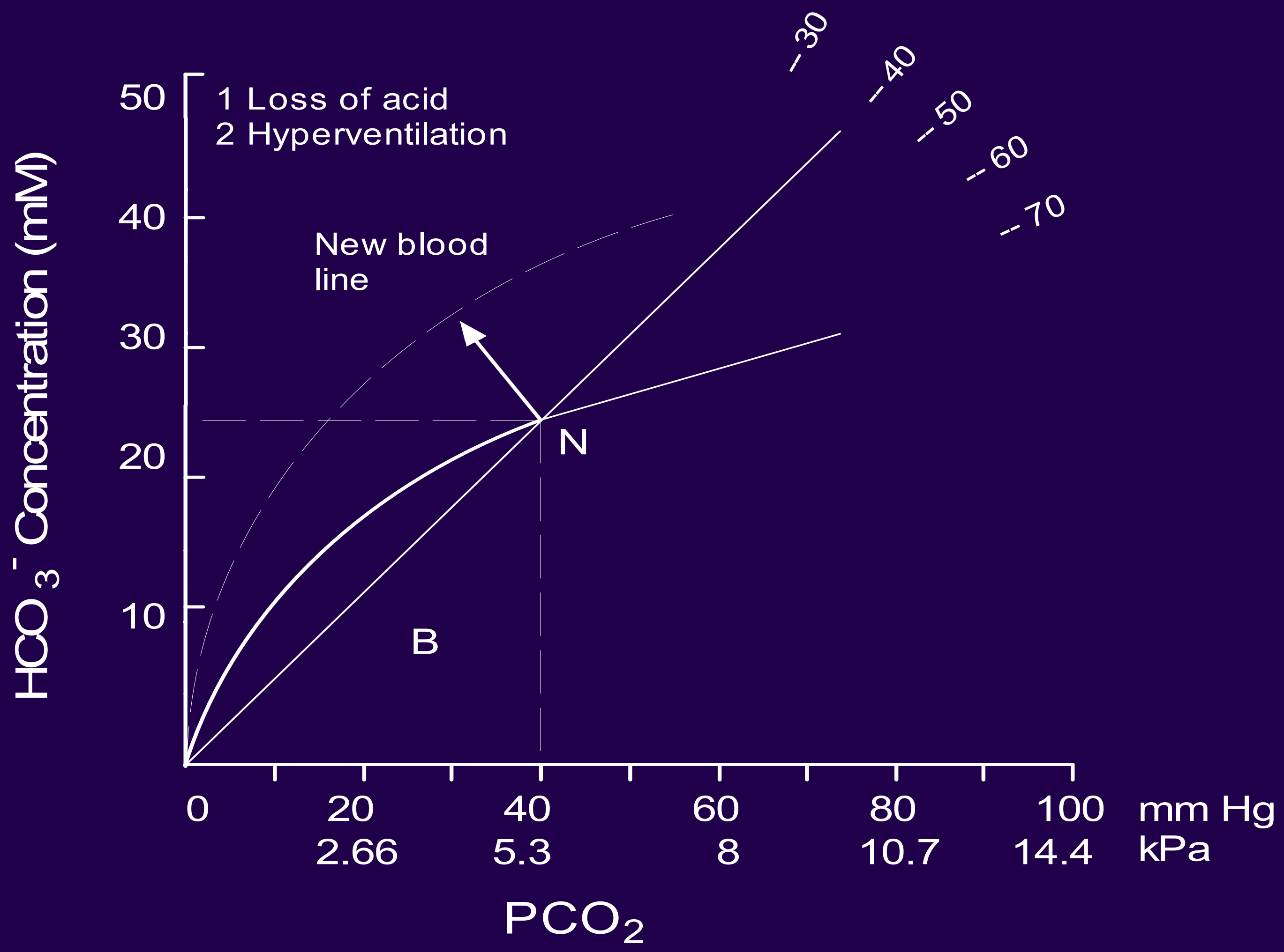


Principles of Acid-base balance interpretation

- 45 yr. old female
- Post bowel surgery
- IPP ventilation
- Naso-gastric suction

pH	7.65
pCO_2	4.0 kPa
pO_2	11.6 kPa
HCO_3^-	32
BE	10 mM

Principles of Acid-base balance interpretation



Principles of Acid-base balance interpretation

- 75 yr. old male
- Smoker 30+ many yr.
- Severe COAD
- Frequent hospitalization with acute exacerbation

pH	7.35
pCO_2	7.9 kPa
pO_2	8.0 kPa
HCO_3^-	35
BE	8 mM

Principles of Acid-base balance interpretation

- 35 yr. old male
- Fit athlete
- Astronomer
- Relocated to site observatory 10,000 ft
- Blood gases at 1 mth

pH	7.35
pCO_2	3.8 kPa
pO_2	11.5 kPa
HCO_3^-	18
BE	- 5 mM

The End